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Sustainable Geotechnics—Theory, Practice, and Applications

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Today, modern Geotechnical Engineers, who in the past would have considered the phenomena occurring in the (primarily soil) environment, are faced with developments in environmental sciences that are becoming more and more detailed and sophisticated, with the natural phenomena and processes surrounding the civil engineering infrastructure being modelled, designed, monitored, and assessed in a more holistic way. This Special Issue aimed to bring together the state of the art in Geotechnics with a focus on sustainable design, construction, and monitoring of the performance of geotechnical assets from ground investigations through foundation and drainage design, to soil stabilization and reinforcement. Submissions from engineers and scientists working in the fields of green infrastructure, nature-based solutions, sustainable drainage, eco-engineering, hydro-geology, landscape planning, plant science, environmental biology or bio-chemistry, earth sciences, GIS, and remote sensing were solicited to highlight significant geotechnical components or applications. Case studies showcasing the application of the sustainable development principles (e.g., reuse, recycle, reduce; stakeholder engagement; public health; UN Global Sustainability Goals) in Geotechnics were also welcomed.

This Special Issue was a success in terms of engaging with geotechnical engineers and researchers worldwide who have keen interest in a wide variety of geotechnical issues and are willing to share their experience and expertise in application of the sustainable development concepts in their work. As a result, in this Special Issue, you will be able to read about potential sustainable approaches in transportation geotechnics, urban environment and water resource management.

Attempting to summarize and highlight the points made in this Special Issue, without spoiling the pleasure of reading the papers for you, I would start with a basic concept in Geotechnical Engineering—the shear strength of soils—which is the *fil rouge* which accompanies the reader through this volume.

Pham and co-authors [1] present a novel hybrid soft computing model using Random Forest and Particle Swarm Optimization for estimation of undrained shear strength of soil based on the clay content, moisture content, specific gravity, void ratio, liquid limit, and plastic limit. Applicable to the whole design range of geotechnical engineering (e.g., foundation design, earth and rock fill dam design, highway and airfield design, stability of slopes and cuts, and in the design of coastal structures), this model is based on the experimental results of 127 soil samples from a national highway project in Vietnam, and they were used to generate datasets for training and validating the model. The results of the model comparison showed that the proposed hybrid model has a high accuracy in the prediction of shear strength of soil and is superior to the single RF model without optimization. Thus, the proposed hybrid model (RF-PSO) can be used for accurate estimation of shear strength, which can be used for the suitable designing of civil engineering structures.

Without adequate shear strength of the soil, the effects of climate change, combined with the urbanization and other anthropogenic effects, will adversely affect the stability of natural and man-made infrastructure, as demonstrated in the study by Bezzer et al. [2], who used sustainable techniques for mapping landslides in an urban area in Brazil. Landslides are part of the natural processes occurring on the Earth's surface, and their occurrence is accelerated and triggered by anthropic interference. Inadequate occupation of areas



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highly susceptible to landslide processes is shown to be the principal cause of accidents on Brazilian urban slopes, especially those occupied by settlements and slums. In their study, Bezzera and co-workers showed that the existence of areas with steep and densely occupied slopes makes the entirety of the municipality area susceptible to landslides. In this context, their study aimed to map the risk of landslides in an urban area using a quali-quantitative model which applies a multicriteria analytical hierarchy process (AHP) to a Geographic Information System (GIS), 11 risk indicators were submitted to pairwise comparisons by 10 risk management specialists in order to determine the relative importance (weighting) for each of these factors as a function of their contribution to the risk. The weightings obtained were combined to produce the final risk map of the study area, using a map algebra framework. The results showed that there is an existing critical risk for the resident population, and to the sustainability in general, primarily related to the possibility of a landslide, with potentially negative economic, environmental, and mainly social impacts.

To improve the strength of the soil and minimize the risks of such natural disasters, novel, sustainable materials are needed. Liu and co-workers [3] used calcium sulfoaluminate cement (CSA) to stabilize a type of marine soft soil in China. They tested the unconfined compressive strength (UCS) of CSA-stabilized soil and compared it to ordinary Portland cement (OPC); meanwhile the influence of amounts of gypsum in CSA and cement contents in stabilized soils on the strength of stabilized soils were investigated. X-ray diffraction (XRD) tests were employed to detect generated hydration products, and scanning electron microscopy (SEM) was conducted to analyze microstructures of CSA-stabilized soils. The results of their study, while offering an insight into the micro-structure of stabilized soils, also showed that UCS of CSA-stabilized soils firstly increased and then decreased with contents of gypsum increasing from 0 to 40 wt.%, and CSA-stabilized soils exhibited the highest UCS when the content of gypsum equaled 25 wt.%. Similarly, Cislaghi et al. [4] present a case for biodegradable geogrids leading towards more sustainable materials for geo-environmental engineering. While plastic materials are widely used in geotechnical engineering, especially as geosynthetics, the use of plastic-based products involves serious environmental risks caused by their degradation. The research presented here was focused on biodegradable polymers of natural origin, especially on polylactic acid (PLA), to reduce the use of plastics. Their study aimed to explore the potentiality of biopolymers for the production of geogrids, measuring the chemical and mechanical characteristics of raw materials and of prototype samples, similar to those available on the market. First, chemical composition and optical purity were determined by hydrogen nuclear magnetic resonance ($^1\text{H-NMR}$) and polarimetry. Furthermore, samples of uniaxial and biaxial geogrids were custom-molded using a professional 3D printer. Mechanical properties were measured both on the filament and on the prototype geogrids. The results of this study showed that the maximum tensile resistance for the neat-PLA filament was smaller than the one for uniaxial prototype geogrids produced with PLA-based polymers mixed with titanium dioxide. PLA-based materials showed higher tensile properties than polypropylene (PP), the most common petroleum derivative. Conversely, such biomaterials seem to be more brittle and have a scarce elongation rate with respect to PP. Nonetheless, the results of this study are encouraging and can support the use of PLA-based materials for innovative biodegradable geosynthetics production, especially if used sustainably in combination with live plants.

However, sustainable materials contributing to the increase in soil strength would have little value without appropriate planning and design procedures and strategies. On those lines, Al-Janabi et al. [5] offer a case study for experimental and numerical analysis for earth-fill dam seepage, while Wallace et al. [6] demonstrate how adopting erosion control measures can reduce the land required to accommodate temporary and permanent sustainable drainage measures.

In the former study, earth-fill dams, which are the most common and most economical type of dam, but also more vulnerable to internal erosion and piping due to seepage problems, which are the main causes of dam failure, are analyzed in terms of seepage

using physical, mathematical, and numerical models. The results from the three methods revealed that both mathematical calculations and the numerical model have a conjectured seepage line compatible with the observed seepage line in the physical model. However, when the seepage flow intersected the downstream slope and when piping took place, the use of numerical modelling to calculate the flow rate became obsolete as it was unable to calculate the volume of water flow in pipes. This was revealed by the big difference in results between physical and numerical models in the first physical model, while the results were compatible in the second physical model when the seepage line stayed within the body of the dam and low compacted soil was adopted. Numerical seepage analysis for seven different configurations of an earth-fill dam (four homogenous dams and three zoned dams) was conducted at normal and maximum water levels to find the most appropriate configuration among them. This revealed that if a sufficient quantity of silty sand soil is available around the proposed dam location, a homogenous earth-fill dam with a medium drain length of 0.5 m thickness is the best design configuration. Otherwise, a zoned earth-fill dam with a central core and 1:0.5 Horizontal to Vertical ratio (H:V) would be preferable.

In the latter study, Wallace et al. [6] demonstrate the development of a methodological Framework for estimating temporary drainage capacity to inform land requirements for a highway construction project in Scotland. Silt pollution generated during major highway construction projects can prove detrimental to the water environment and the aquatic species that depend on it. Construction activities can leave many kilometers of exposed soil susceptible to erosion from surface water runoff, which can result in silt pollution and degradation of ecologically sensitive watercourses if appropriate mitigation is not in place. In Scotland, assurances need to be provided during scheme development to demonstrate that there is sufficient space to accommodate temporary drainage. In response, a methodological framework has been developed that can be applied before construction commences to estimate the required capacity of settlement ponds, including runoff and soil loss volume estimation. The application of the framework as a case-study demonstrated the potential applicability of the approach and highlighted where further refinements can be made to increase the robustness for future applications by improving the accuracy of input parameters to address site-specific conditions. Furthermore, it demonstrated how adopting erosion control measures can reduce the land required to accommodate sustainable drainage measures, such as temporary settlement ponds.

Bearing in mind that the geographical spread of the research presented in this Special Issue includes Asia, South America, and Europe, it is clear that there is solid awareness of the sustainability in Geotechnical Engineering worldwide, and the geotechnical engineers and researchers work tirelessly to provide innovative solutions for the infrastructure, which should resist the effects of climate change and can be applied worldwide. However, to successfully combat the growing climate change challenges and work towards sustainable and healthy communities, geotechnical engineers should embrace the sustainability approaches (e.g., green infrastructure, nature-based solutions, ground bio-engineering, sustainable drainage; Mickovski [7]) while aiming for the achievement of multiple sustainable development goals. Ending this Editorial, I would encourage you to browse through this Special Issue and thank you for continuing support of sustainability in Geotechnics.

Conflicts of Interest: The author declares no conflict of interest.

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